PETROLOGY OF TALC DEPOSITS AND ASSOCIATED PRECAMBRIAN METAMORPHIC ROCKS, SOUTHWESTERN MONTANA

Faculty
John Brady, Smith
John Cheney, Amherst

Students
Mathieu Duvall, Colorado
Christopher Green, Amherst
Lewis Kaufman, Wooster
Ari Kogut, Beloit
Amy Larson, Smith
Angela Vesquez, Amherst

Visitors
Eiler Henrickson, Colorado

Talc Deposits of the Ruby Range, Southwestern Montana

John B. Brady (Geology Department, Smith College, Northampton, MA 01063)
John T. Cheney (Department of Geology, Amherst College, Amherst, MA 01002)

Introduction

Extensive deposits of pure talc have been mined in southwestern Montana for over 50 years (Olson, 1976; Berg, 1979). A number of mines in the region are still active and additional mines are expected to open in the near future. Mining of talc is economic because of the very high purity and large extent of the deposits. Ore zones that are virtually 100% talc can be traced for several hundred meters. The talc deposits are confined, stratigraphically, to marble units in an Archean metasedimentary sequence and previous workers have concluded that the talc has formed by a metasomatic replacement of the marble. The scale of the talc occurrences, the significant chemical differences between pure talc and the Archean marbles, and the small number of minerals present in most samples suggest that a large scale fluid flow system was required for the formation of the deposits.

The Keck Montana Project was undertaken to constrain, quantitatively, possible scenarios for talc formation in the Ruby Mountains. In particular, we hoped to (1) identify or confirm the mineral assemblages that occur in and around the talc deposits, (2) determine the range of physical conditions under which the talc formed, (3) determine the range of fluid compositions that might have equilibrated with these rocks, and (4) determine the relative and perhaps absolute timing of the metasomatic processes. The abstracts that follow are progress reports on the detailed findings of the six student participants. The remainder of this abstract will provide a context in which to view the student findings.

Regional Geology

The Ruby Mountains are one of a group of Archean-cored, block-faulted mountain ranges that dominate the skyline of southwest Montana. Although a structurally complex region of Paleozoic and Mesozoic rocks occupies the relatively inaccessible northern portion of the range, the bulk of the Ruby Mountains consists of spectacularly deformed Archean metasediments and meta-igneous rocks (Fig. 1). Geologic maps are available for much of the range due to the careful work of Okuma (1971), Garihan (1973), Tysdal (1976), Karasevich *et al.* (1981), and James (1990). Most of the talc occurs in the western half of the Ruby Range in marbles of the Christensen Ranch Metasedimentary Suite, formerly called the Cherry Creek Group (James, 1990). Although the name Cherry Creek may be discarded, the unique suite of rocks ranging from banded iron formation to sillimanite schist to anthophyllite gneiss to coarse-grained marble remains distinctive. East of the metasedimentary sequence is a thick quartzofeldspathic gneiss ("Dillon Granite Gneiss") that has been described as an intrusive rock by many, but the protolith of this gneiss is a matter of debate (Karasevich *et al.*, 1981). Still further east is a possibly older suite of metamorphic rocks that are generally lacking in marbles and, therefore, lacking in talc deposits. Serpentinized ultramafic rocks occur among the "older gneisses" in the southeastern part of the range, but are not spatially associated with the talc studied (Desmarais, 1981).

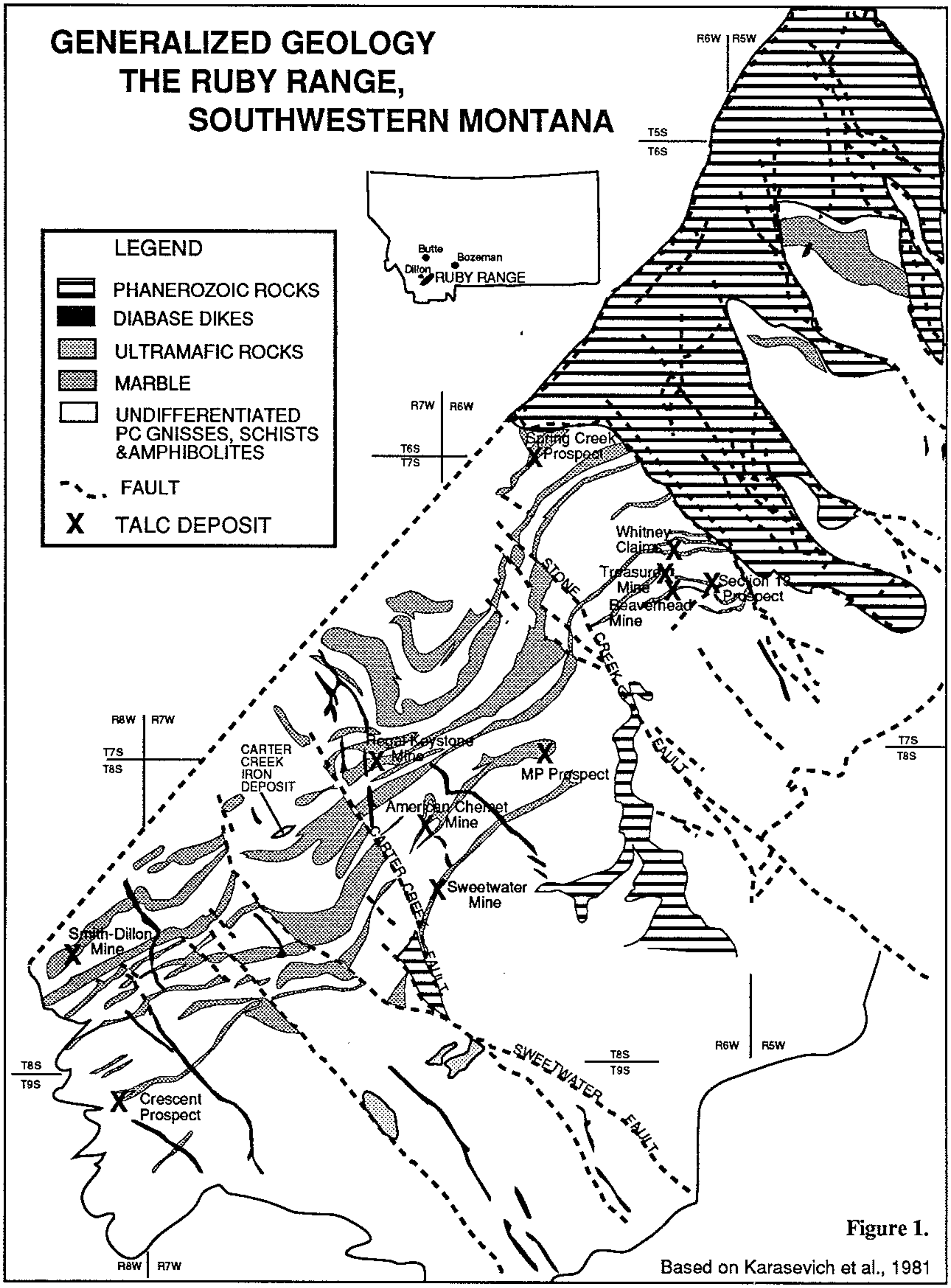

Figure 1.

Based on Karasevich et al., 1981

The Archean rocks were deformed and metamorphosed to upper amphibolite facies conditions at approximately 2.7 Ga. This age is based on Rb/Sr dating of gneiss samples from the Ruby Range by James and Hedge (1980) and is consistent with ages determined for Archean rocks in nearby ranges (Wooden, Mueller, and Moek, 1988). Based on mineral assemblage thermobarometry, Dahl (1979) determined that peak conditions for the Archean metamorphism were 650°-750°C and 5-7 kbar. We observed migmatite zones in some of the gneisses, which we interpret as evidence for partial melting during Archean metamorphism. The marbles developed a coarse texture and the mineral assemblage calcite-diopside-forsterite-phlogopite-graphite.

Many of the Archean metamorphic rocks of the Ruby and nearby ranges have a patchy overprint of greenschist facies mineral assemblages. Whether this overprint developed (1) as a retrograde metamorphism during (Archean?) cooling from upper amphibolite facies conditions, (2) as a regrading during some later period of regional heating, or (3) as a regrading during the talc-forming event is not yet known. Giletti (1966) obtained K/Ar and Rb/Sr ages of 1.4 to 1.7 Ga on minerals and rocks of the Ruby Range and concluded that there was a 1.6 Ga Proterozoic thermal event that reset the isotopic clocks. Although Giletti analyzed fresh rocks, James (1990) and others have postulated that the 1.6 Ga date coincides with the regional development of greenschist facies mineral assemblages. A number of workers have also suggested that talc formation was associated with this thermal event (*e.g.* Berg, 1979). This interpretation may be at odds with data concerning faulting and diabase dikes.

The map of the Ruby Range is punctuated by a series of NW-trending faults that clearly offset the Christensen Ranch Metasedimentary Suite (Fig. 1). Faults with the same trend are common in the surrounding ranges as well. Some of the talc deposits appear to have been localized by NW-trending faults (Garihan, 1973) and, therefore, post-date at least some of the movement along theses faults. Schmidt and Garihan (1986) have demonstrated repeated movement along these faults beginning in the Proterozoic Era. For example, two groups of unmetamorphosed diabase dikes that have been Rb/Sr dated at 1.1 and 1.4 Ga (Wooden et al., 1978), are widespread in the region. These dikes typically have a NW-trend and a few appear to directly follow the trace of NW-trending faults. Therefore, it is believed that the diabase dikes post-date the initiation of movement along the NW-trending faults. Regionally, these faults and the associated diabase dikes have been attributed to the extensional tectonics that led to the creation of the Belt Basin (Wooden *et al.*, 1978; Schmidt and Garihan, 1986). Matt Duvall (this volume) addresses the relative timing of talc formation and diabase intrusion. Chris Green (this volume) further explores the relationship between alteration and faults and is preparing samples for $^{40}Ar/^{39}Ar$ dating of the talc deposits.

Talc Deposits

Previous studies (Okuma, 1971; Garihan, 1973; Olson, 1976; Berg, 1979; Anderson *et al.*, 1990) have shown that the Ruby Range talc deposits (1) are restricted to Archean marbles, (2) are commonly associated with fold noses, faults, and contacts between marbles and other rock types, (3) contain the mineral assemblage talc-dolomite-chlorite$\pm$graphite$\pm$calcite, and (4) required considerable quantities of silica-bearing fluid to form. These observations have been added to and extended by Lewis Kaufman, Ari Kogut, and Angela Vasquez (this volume).

All workers listed above have emphasized that talc occurrences are restricted to dolomite marbles and that they are not found in the calcite marbles. However, Anderson *et al.* (1990) were the first to point out that much of the dolomite in these marbles post-dates the Archean metamorphism. They cited a number of convincing textural and mineralogic features of the dolomite occurrences. Lewis Kaufman (this volume) has obtained additional evidence bearing on the dolomitization and its relationship to the talc. A plausible model is that the dolomite and talc were formed contemporaneously and sequentially by circulation of the same fluids. As in a chromatographic experiment, dolomite then talc may form at sequential fronts of infiltration metasomatism by an Mg-Si-rich fluid (Korzhinski, 1970; Hofmann, 1972). This model is consistent with the high thermodynamic variance of the observed mineral assemblages and with the high calculated volumetric fluid to rock ratios (600:1 - Anderson *et al.*, 1990).

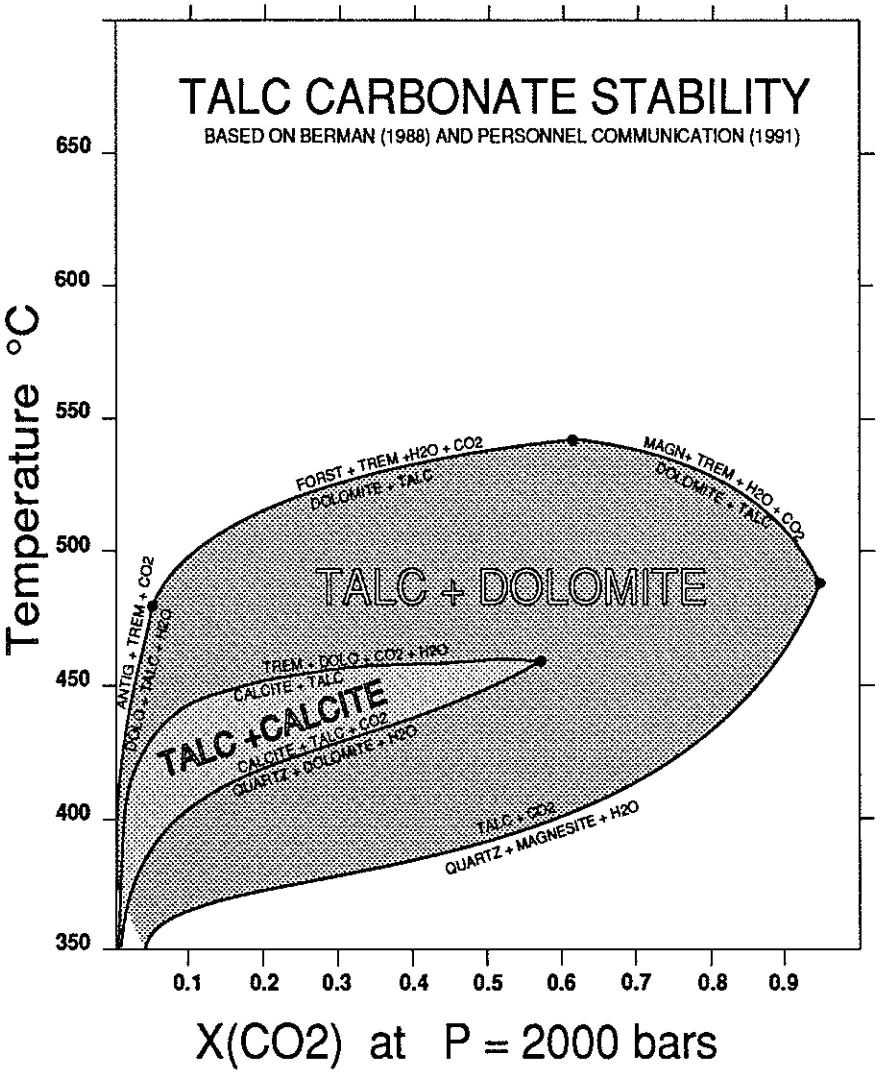

Figure 2. Calculated talc-dolomite and talc-calcite stability relations.

Based on the observed mineral assemblages talc-calcite and talc-dolomite, important constraints on the physical conditions can be obtained from experimental studies. Because both water and carbon dioxide are involved in the talc-forming reactions, the mole fraction of CO_2 in the talc-forming fluids (principally an H_2O-CO_2 fluid?) is as important as temperature and pressure in locating reactions. Relevant chemical reactions calculated from Berman's (1988) thermodynamic data set are shown as a function of temperature and mole fraction of CO_2 (X_{CO2}) in Figure 2. Clear upper limits on temperature and mole fraction of CO_2 are visible in Figure 2 for the assemblages talc-calcite and talc-dolomite. Unfortunately, useful lower limits for either temperature or mole fraction of CO_2 are not apparent. Based on the large volume of fluid required, it is likely that the fluid had a low mole fraction of CO_2. Amy Larson (this volume) is measuring the carbon isotopic composition of dolomite and graphite to obtain temperatures with the dolomite-graphite geothermometer. Chris Green (this volume) is attempting to constrain the temperatures and pressures of various events on the basis of mineral assemblage thermobarometry.

Anderson *et al.* (1990) suggested Mg-rich sea water as a candidate for the talc-forming fluids. This is consistent with a model of talc formation coinciding with the development of the Belt Basin. Angela Vasquez and Amy Larson (this volume) present oxygen isotopic data on marbles that test the seawater hypothesis and constrain the volume of fluid required. Ari Kogut and Matt Duvall (this volume) also present geochemical data relevant to the seawater hypothesis. Based on oxygen isotopic data, deep circulation of seawater has been proposed by Wickham and Taylor (1987) as part of a Hercynian rifting event in the Pyrenees. Their oxygen and carbon isotope data on carbonates match closely those obtained by Amy Larson and Angela Vasquez for the Ruby Range. Perhaps the Hercynian tectonics and metamorphism of the Pyrenees are a younger analog for Proterozoic tectonics and metasomatism in Montana.

References Cited

Anderson, D.L., Mogk, D.W., and Childs, J.F. (1990) Petrogenesis and timing of talc formation in the Ruby Range, southwestern Montana: *Economic Geology*, **85**, 585-600.

Berg, R.B. (1979) Talc and chlorite deposits in Montana: Montana Bureau of Mines and Geology Memoir 45, 66p.

Berman, R.B. (1988) Internally consistent thermodynamic data for minerals in the system Na_2O-K_2O-CaO-MgO-FeO-Fe_2O_3-Al_2O_3-SiO_2-TiO_2-H_2O-CO_2: *Journal of Petrology*, **29**, 445-522.

Dahl, P. (1979) Comparative geothermometry based on major element and oxygen isotope distributions in Precambrian metamorphic rocks from southwestern Montana: *American Mineralogist*, **64**, 1280-1293.

Desmarais, N.R. (1981) Metamorphosed Precambrian ultramafic rocks in the Ruby Range, Montana: *Precambrian Research*, **16**, 67-101.

Garihan, J.M. (1973) Geology and talc deposits of the central Ruby Range, Madison County, Montana: Unpublished Ph.D. Dissertation, Pennsylvania State University, 209p.

Giletti, B. (1966) Isotopic ages from southwestern Montana: Journal of Geophysical Research, **71**, 4029-4036.

Hofmann, A. (1972) Chromatographic theory of metasomatic zoning: *American Journal of Science*, **272**, 69-90.

James, H.L. (1990) Precambrian geology and bedded iron deposits of the southwestern Ruby Range, Montana: U.S. Geological Survey Professional Paper 1495, 39p.

James, H.L. and Hedge, C.E. (1980) Age of the basement rocks of southwest Montana: *Geological Society of America Bulletin*, **91**, 11-15.

Karasevich, L.P., Garihan, J.M., Dahl, P.S., and Okuma, A.F. (1981) Summary of Precambrian metamorphic and structural history, Ruby Range, southwest Montana: Geological Society of Montana 1981 Field Conference Guidebook, 225-237.

Korzhinskii, D.S. (1970) *Theory of metasomatic zoning:* Oxford University Press, 162p.

Okuma, A.F. (1971) Structure of the southwestern Ruby Range near Dillon, Montana: Unpublished Ph.D. Dissertation, Pennsylvania State University, 122p.

Olson, R.H. (1976) The geology of Montana talc deposits: Montana Bureau of Mines and Geology Special Publication 74, 99-143.

Schmidt, C.J. and Garihan, J.M. (1986) Middle Proterozoic and Laramide tectonic activity along the southern margin of the Belt basin: Montana Bureau of Mines and Geology Special Publication 94, 217-235.

Tysdal, R.G. (1976) Geologic map of northern part of Ruby Range, Madison County, Montana: U.G. Geological Survey Miscellaneous Investigations Series, Map I-951.

Wickham, S.M., and Taylor, H.P, Jr. (1987) Stable isotope constraints on the origin and depth of penetration of hydrothermal fluids associated with Hercynian regional metamorphism and crystal anatexis in the Pyrenees: *Contributions to Mineralogy and Petrology*, **95**, 255-268.

Wooden, J.L., Mueller, P.A., and Mogk, D.W. (1988) A review of the geochemistry and geochronology of the Archean rocks of the northern part of the Wyoming Province: **in** W.G. Ernst, ed., *Metamorphism and Crustal Evolution of the Western United States*, Prentice-Hall, Englewood Cliffs, NJ, 383-410.

Wooden, J.L., Vitaliano, C.J., Koehler, S.W., and Ragland, P.C. (1978) The late Precambrian mafic dikes of the southern Tobacco Root Mountains, Montana: Geochemistry, Rb-Sr geochronology, and relationship to Belt tectonics: *Canadian Journal of Earth Science*, **15**, 467-479.

The Petrology of Mafic Dikes and Their Relationship to Talc Formation in the Ruby Range
Southwestern Montana

Mathieu L. Duvall
Geology Department, Colorado College

Introduction

The goal of the Montana project was to form a complete petrogenetic model for the formation of economic talc deposits in the Ruby Range, southwestern Montana. Many workers (e.g. Anderson et al., 1990 and Garihan, 1973) have studied the genesis of the talc bodies and possible mechanisms for their formation. However, the exact age and the corresponding thermal event for talc formation have not yet been determined.

Based on chronological associations, one thermal source proposed by Anderson et al., (1990) is the intrusion of mafic dikes at 1455 Ma and 1130 Ma. Mafic dikes are observed cutting across talc deposits in two locations at the Regal-Keystone talc mine and one location at the Smith-Dillon mine. These locations, while undocumented by previous workers, seem the ideal places to determine the thermal and chronological relationship between the dikes and the talc deposits. A study of the mafic dikes of the Ruby Range was undertaken to A) chemically and petrographically characterize the mafic dikes of the Ruby Range and B) determine the relationship between the talc deposits and the dikes.

Field work and Petrography

Based on field and petrographic observations, the dikes were divided into two general groups: 1) Archean amphibolite dikes, and 2) Proterozoic diabase dikes. The group 2 rocks were divided into two separate sub groups consisting of a) fresh dikes and b) very altered dikes. In hand sample the group 1a rocks appeared to be fresh amphibolite while the group 1b rocks had obviously undergone extensive alteration. The group 2 rocks all appeared to be fresh except for localized epidotization.

In thin section, however, all of the dike samples taken showed varying degrees of alteration. While the original mineralogy may still be intact, alteration rims can be seen even on the freshest of samples. Chlorite and sericite are present in varying amounts in all of the dikes.

The group 1a rocks consist predominately of amphibole (>40%) and plagioclase, with varying amounts of chlorite, sericite and quartz. Accessory minerals included epidote, biotite, opaques and garnet. These rocks are amphibolites and have been subjected to high grade regional metamorphism. They are therefore considered to be Archean age because no high grade regional event is beleived to have occurred in the Proterozoic.

The group 1b rocks consist of chlorite (80-90%) quartz and opaques. Minor amounts of talc are seen as well. The presence of talc suggests that the hydrothermal event responsible for the alteration of these dikes was also responsible for talc formation.

The group 2 rocks are diabasic in texture and consist of predominately plagioclase and clinopyroxene. Accessory minerals include quartz, opaques, and biotite. The plagioclase is commonly altered to sericite and the pyroxene to chlorite and more rarely amphibole. These rocks lack the high grade mineral assemblage seen in the group 1 rocks.

Geochemistry

Twenty four of the samples selected for thin section analysis were analyzed for major and trace element geochemistry by x-ray flourescensce on a Rigaku 3070 x-ray spectrometer. Eighteen of these samples were submitted for Rare Earth Element (REE) analysis by Induced Nuetron Activation Analysis techniques.

Major element chemistry for the group 1a and group 2 rocks is very similar. They both have about 50 weight percent SiO_2, 6 to 7 weight percent MgO, and 1.5 to 2.5 weight percent Na_2O. They all plot as high Fe tholeiites on a Jensen cation diagram (1976) (Fig. 1). In fact, they plot overwhelmingly as tholeiites on every classification diagram used in this study. The group 1b rocks, however, show distinct enrichment of MgO (20 to 30 weight percent MgO) and depletion in SiO_2 (42to44 weight percent), Na_2O (0 weight percent) and Calcium (< 2 weight percent) (Fig.2).